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Strategy for Promoting the Basic Capabilities of Frontier New Materials Industry

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Abstract: In this study, we focus on the current status and problems regarding the basic capabilities of the frontier new materials industry in advanced fields such as brain-like intelligence, artificial intelligence, deep-space exploration, network security, and efficient energy conversion. Considering the phased development plans for 2025 and 2035, we propose development goals and strategies for promoting the basic capabilities of the frontier new materials industry in China, in terms of scientific and technological innovation, support, competitiveness, sustainable development, infrastructure construction, and the industrial environment. To meet the requirements of the new round of scientific and technological revolution and industrial transformation for frontier new materials, countermeasures and suggestions are proposed from the perspectives of material genetic engineering, double circulation, carbon peak and carbon neutrality, and the testing and characterization of independent frontier new materials.
Keywords: frontier new materials; basic industrial capacities; cutting-edge science and technology; material genetic engineering; double circulation; carbon peak and carbon neutrality

1 Introduction

Frontier new materials drive strategic emerging industries, and fuel future technological development. These materials exhibit excellent properties and unique functionalities. The frontier new materials industry is characterized as strategic, pioneering, disruptive, possessing strong industrial drive, and high added value. The development of the frontier new materials industry carries great significance as a key factor in determining the sophistication levels of high-end manufacturing and national defense equipment.

Brain-like intelligence, artificial intelligence (AI), deep-space exploration, network security, and efficient energy conversion are key areas in the research and application of frontier new materials [1–5]. (1) For the brain-like intelligence field, frontier new materials are divided into brain-like intelligent perceptual materials, brain-like intelligent functional materials, brain-like functional repair materials, intelligent and strong brain frontier new materials, etc. These materials are used to achieve machine intelligence with brain-like information processing mechanisms, human-like cognitive behavioral performance, and intelligence levels up to or beyond those of humans. (2) For the AI field, frontier new materials have been developed to meet the needs of AI and its cross-fertilization industries and to provide multi-functionality and intelligent functions. As compared to those of traditional materials, the comprehensive properties and sensing, processing, and responding abilities to the environment of frontier new materials in the AI field are better. These materials are divided into intelligent polymers, lightweight functionalized

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metals, mechanically-sensitive composites, etc. (3) For deep-space exploration, frontier new materials are used in deep-space probes that work on various complex settings, such as ultra-low temperatures, strong radiation, vacuum condition, zero (micro) gravity, and planetary atmospheres and surfaces. These materials are divided into new generation ablative thermal protection, thermal managing, low-temperature lubricant, dustproof/self-cleaning, buffering and energy absorbing, etc. (4) For the network security field, frontier new materials are classified as multi-banded/low-dimensional absorbing and shielding and quantum information memory. These materials are also used to guarantee the confidentiality, integrity, availability, controllability, reviewability, and secure transmission of network information. (5) For efficient energy conversion, frontier new materials are classified as photoelectric photothermal, thermoelectric, piezoelectric, electroluminescent, chemical-electric, and magnetic-mechanical materials. These devices have the following advantages: high conversion efficiency, high degree of safety, high structural stability, long service life, low cost, and low environmental load.

There is an uneven development of the global frontier new materials industry and the prolonged accumulation of differences in high-tech industries and high-end manufacturing between countries and regions. These conditions have led to a three-tier competitive pattern in the current global frontier new materials industry. The United States, Japan, Europe, and other developed countries and regions are in the first echelon, with evident advantages in frontier new materials research and development (R&D) strength, basic industrial capacity, and market share; China, South Korea, and Russia are in the second echelon, all developing at a high speed; India, Brazil, and other countries are in the third echelon, and are struggling to catch up.

With the promotion of industrial policies, such as action plans for frontier new materials in strategic and emerging industry clusters, the development of the frontier new materials industry in China has gained momentum. However, there remains a lack of major, original innovation capacity. Moreover, key technologies, auxiliary raw materials, equipment, and high-end inspection and testing instruments are subject to heteronomy. It will be necessary to provide forward-looking top-level designs for the frontier new materials industry development, and actively leverage the advantages of the new nationwide system to improve the basic capacities for science and technology innovations, support and guarantee, competitiveness, and sustainable development of the frontier new materials industry and improve the ecological environment. In view of the multidisciplinary, innovative, and disruptive characteristics of frontier new materials, interdisciplinary and innovative industrial talents should be cultivated, and common frontier key technologies, such as material genetic engineering, should be fully integrated in the industry to promote a leapfrog development.

2 Development status of basic capabilities of frontier new materials industry

2.1 Brain-like intelligence field

Frontier new materials are leading in the development of brain-like intelligence technologies and a new round of technological revolution. However, the industrial foundation of these materials in the domestic brain-like intelligence field is relatively weak. There is a serious lack of new materials with intellectual property rights, software for key equipment, major products and system designs, and high-end talent teams. Additionally, certain key auxiliary raw materials are monopolized by foreign countries, and the security of the industrial chain is at high risk. Regarding brain-like, intelligent perception materials, nearly 30% of high-purity, synthetic organic reagents for key auxiliary raw materials are entirely dependent on imports. Moreover, high-end photoresists for advanced and fine lithography technology are dependent on imports.

2.2 Artificial intelligence field

The foundation and technologies of the AI industry are constantly evolving and progressing its applications. Currently, many technology companies are targeting their R&D resources on brain-like chips, quantum computing chips, intelligent electronic devices, and other underlying technologies. The focus of research on the AI industry chain has shifted to the basic layer. In the development of the frontier new materials industry for AI, China suffers from insufficient mastery of core technologies, overcapacity in the middle and low ends, and insufficient security for high-end products, key materials, and core processes. These problems are stem from the lack of scientific and technological innovation capacity, the late start of industrial development, and a weak industrial foundation. The imported proportion of key components, core processes, and high-performance materials remains high, hindering China from entering the next stage. For example, copper foil is a key material in copper-clad panels. However, in China, there is no technological system with independent intellectual property rights for the core processes of copper

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and copper alloy rolling, copper foil surface treatment, or processes for other key auxiliary raw materials. Moreover, majority of the output are supplied to a low-end market, and there is a large gap between the domestic and advanced international levels regarding the comprehensive technicality, quality stability, and product reliability.

2.3 Deep-space exploration field

Deep-space exploration has a small platform, low material usage, high performance requirements, and immense technical difficulty, and is an important part of the aerospace industry. The domestic frontier new materials industry in this field has a robust capacity and guarantees the implementation of a series of major tasks in deep-space exploration and space science. However, the basic capabilities of science and technology innovation are lacking with regards to application of these materials in the deep-space exploration field. To be precise, its core capability is at the following stage. The study of ablative thermal protection materials (e.g., glass-fiber honeycomb-filled phenolic resin ablative materials and phenolic resin impregnated carbon matrix ablative materials) and thermal management materials (e.g., nano-aerogels and intelligent thermal control coatings) have been pioneered by developed countries. Only a few materials, such as super-hydrophobic dustproof materials, have been promoted by Chinese scientists. The properties and output of the key materials require improvement. For example, the key technical indicators of carbon fibers with high strength and high or extremely high modulus, which are widely used for space structures, require further breakthroughs, as well as established and independent production capacity. For the domestic deep-space exploration field, frontier new materials R&D is mainly addressed by research institutes, universities, and state-owned aerospace enterprises. A market-oriented operation mechanism has been lacking for a long time, and a large-scale production is yet to be established.

2.4 Network security field

Network security is related to economic and social development, as well as national security. The infrastructure for the frontier new materials industry in this field is largely complete and provides significant support to R&D of related materials. Certain core technologies, such as fifth-generation mobile and quantum communication, are at the forefront of the world. However, the key materials and components involved in these technologies remain dependent on imports, which restricts its application and promotion. In the field of network security, the infrastructure capacity of science and technology innovation for frontier new materials is lacking. Self-developed products have difficulty meeting the comprehensive requirements of being thin, wide, light, and strong, prior to filtering, absorbing, and shielding materials application. The scale of skilled personnel in related fields is also insufficient, as is the participation of the enterprises. Overall, the industry competitiveness in this field is weak.

2.5 Efficient energy conversion field

Efficient energy conversion materials provide significant support and basic guarantees for the construction of major projects, development of national defense equipment, and formation of an energy-saving and environment-friendly society. The production capacity for efficient energy conversion materials, such as photothermal, thermoelectric, and batteries, is increasing annually while the industrial scale and market share are expanding. Some core technologies achieved substantial breakthroughs and technical indicators improved significantly. However, owing to the late start and weak foundation, evident shortcomings remain with regard to core technology development, innovation capabilities, key products, industrial scale, and major equipment. Thus, there is a large gap between the domestic and international advanced levels. Support in terms of funds, innovation resources, and policies is relatively scattered, and the upstream and downstream sectors of the industry chain are yet to form a collaborative innovation model. Meanwhile, the scientific research institutions and enterprises are disconnected regarding the production, education, research, and application, which has led to majority of materials from this field to be used in low-end products. Moreover, it is difficult to integrate such materials into the global supply system of new materials. The key components, core processes, and basic materials are also highly dependent on imports, which restricts the development and application of frontier new materials. Other problems concerning unsound standards, measurement, and management of new materials in the efficient energy conversion field have not yet been solved. The continuing existence of these problems affects the ability of managing departments and enterprises to make accurate judgments on the development trends of the industry and is not conducive to a reasonable introduction of support measures and precise arrangement of development priorities.

3 Analysis of basic industrial capacities for frontier new materials

Future developments in brain-like intelligence, AI, deep-space exploration, network security, and efficient energy conversion require an input of intelligent polymers, lightweight high-strength high-functioning metals, new inorganic non-metallic materials, as well as multifunctional composites. The development of frontier new materials requires the support of basic industrial capacity, such as raw and auxiliary material supplies, baseline process manufacturing levels, industrial core technologies, basic core equipment, basic key parts/components, basic inspection and testing instruments, and basic industrial software.

The key frontier new materials industry involves nearly 30 main and auxiliary raw materials. Graphene, acrylonitrile, rare earth ore, ilmenite, anode materials for lithium batteries, halogen perovskites, rare earth metals and oxides, indium, gallium, and selenium can be acquired independently (i.e., > 90% of these materials can be guaranteed independently). Bio-sensing gels, phenolic resins, and carnallite are safe and manageable (i.e., 70% or more of the supply can be guaranteed independently). Bauxite depends on imports (> 50% of supply). Photoresists, wafers, electronic special gases, photomasks, wet electronic chemicals, high-purity ferrites, high-purity metal particles, lithium, nickel, cobalt, light-emitting diode (LED) epitaxial wafers, chips, and material databases are also highly dependent on imports (> 80% of the supply).

Among the main and basic manufacturing processes of key frontier new materials, laser etching, high-efficiency and low-cost metal melt additive manufacturing, casting, plastic processing, short-process preparation and processing of layered metal composite materials, ablation-resistant thermal protection material manufacturing, and data mining have reached advanced international levels. Nevertheless, a gap remains between the domestic and advanced international levels on third-generation carbon fiber composite material manufacturing, lithography, lithium-ion battery production, and thermoelectric material preparation. In the future, further breakthroughs will be necessary in laser etching automation and precision, continuous metal flow control and rapid conformal cooling [6], composition uniformity control for large-scale ingots [7], precise extrusion of light alloy profiles, preparation and processing of wide metal clad sheets with high interface bonding strength, and data mining for frontier new materials to maintain or expand towards higher echelon. In the subdivision direction, where the development level lags, it will be necessary to break the blockade caused by core technologies, improve R&D capabilities, and achieve a continuous and independent innovation of key equipment, raw materials, and core technologies.

Among the core technologies for key frontier new materials industries, the Aluminum Corporation of China, Tsinghua University, and Beijing Institute of Aeronautical Materials have reached advanced international levels with regard to aluminum electrolysis technology, brain-like computing, and titanium alloy precision casting. Nata Opto-electronic Material Co., Ltd., Huawei Technologies Co., Ltd., Semiconductor Manufacturing International Corporation, Changjiang Electronics Technology, Yalian Hi-Tech Co., Ltd., Shanshan Energy Co., Ltd., the University of Science and Technology Beijing, the Institute of Metal Research, and the Chinese Academy of Sciences are the dominant domestic developers for certain aspects of core technologies, such as photolithography machines, chip design and manufacture, high-end chip packaging technology and equipment, LED epitaxy materials, lithium battery material preparation technologies, hydrogen production and storage technology, common frontier technologies for material genetic engineering [8,9], and intelligent manufacturing technologies. However, gaps remain between the level of these domestic organizations and the advanced international community. Currently, global competition for the dominance of key and core technologies in key frontier new materials industries is becoming increasingly fierce. For China, increasing the investment in the R&D of key core technologies is imperative to upgrade core technologies of the industry and promote it to a higher level.

Among the basic core equipment of key frontier new materials industries, surface light source manufacturing equipment and intelligent manufacturing equipment have reached advanced international levels. In contrast, there is still a gap between the domestic and advanced international levels on large-scale and precision forging equipment, polysilicon purification equipment, and fuel cell testing equipment (Table 1).

Among the basic key parts/components in the key frontier new materials industries, brain-like computing hardware platforms and laser reflective films have reached advanced international levels. In contrast, there are still gaps between domestic and advanced international level for photolithography machine light sources and lenses, brain-computer interfaces, and high-performance filters and masks (Table 2).

Among the main basic inspection and testing instruments in key frontier new materials industries, static universal testing machines, electrochemical detectors, and electrical performance parameter testers for semiconductor devices have reached advanced international levels. However, gaps remain between the domestic and advanced international levels on scanning electron microscopes, transmission electron microscopy, and high-end oscilloscopes (Table 3).

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Table 1. Level of basic core equipment in the industry.

Basic core equipment	Independent guarantee situation	Extent of gap between domestic and imported equipment
Surface light source manufacturing equipment and intelligent manufacturing equipment	Mainly domestic	The gap is small [10,11].
Ingot furnace, square cutting machine, multi-wire cutting machine, and diffusion furnace	Mainly import	There are evident gaps in efficiency, accuracy, and stability [12,13].
Rolling and extrusion equipment		Domestic equipment is less accurate [14].
Equipment for cell activation, formation, capacity detection, and assembly; battery tester, dicing saw, series welding machine, and laminator		There are evident gaps in efficiency, accuracy, and stability [15].
Large and precision forging equipment		Low precision and high failure rate [16]
Polysilicon purification equipment		Gaps remain in production technology and product purity [17].
Electrolyzer, vehicle-mounted hydrogen tanks, hydrogen compressors, hydrogenation machines, fuel cell testing equipment, and hydrogen detector		There are evident gaps in hydrogen production efficiency, hydrogen storage density, and testing standards [18].

Table 2. Basic key parts/components of the industry.

Basic key parts/components	Independent guarantee situation	Extent of gap between domestic and imported parts/components
Brain-like computing chip	Mainly domestic	Tsinghua University's "Tianji" and Zhejiang University's "Darwin" chips are at the world's leading level [19].
Light sources and lens of photolithography machines	Mainly imports	The energy of the light source is low and the frequency is unstable. The photolithography machine light source is monopolized by foreign countries, and the technology is patented [20].
Brain–computer interface, high-end sensors, high-performance filters, and high-end chips		Low level of signal acquisition and processing, design and manufacturing technology, poor product form and performance [21]
High-pressure integrated bottle valve, pressure reducing valve, and conduit connectors		Poor resistance to high temperature and high pressure, low integration [22]

Table 3. Independent guarantees of main basic inspection and testing instruments.

Main basic inspection and testing instruments	Independent guarantee situation	Extent of gap between domestic and imported instruments
Material universal testing machine	Mainly domestic	The static universal testing machine is equivalent to similar foreign instruments, while there is a large gap between dynamic testing machine and foreign machines [23].
Electrochemical detector, PDA-FS380 semiconductor device electrical performance parameter tester	Mainly imports	Equivalent to similar foreign instruments [24,25]
Voltametric and quantum efficiency test system		Gaps remain regarding efficiency, accuracy, and stability [26,27].
High-throughput material synthesis/detector, and terahertz near-field high-throughput material property testing system		There is a gap in test accuracy [28,29].
Scanning electron microscope and transmission electron microscopy		Mainly imported instruments [30]
High-end oscilloscope, Agilent 4155C semiconductor parameter analyzer, Keysight B1500A semiconductor device analyzer, Keithley 4200A-SCS parameter analyzer, Keithley 2400, 2 600 series digital source meters, and Keithley 6514 electrometer		Mainly a foreign monopoly [31]

Basic industrial software provides a guarantee for intelligent manufacturing, the industrial Internet, and the design and manufacture of many high-tech products. Among the basic industrial software for the key frontier new materials industry, high-throughput computing software, computer-aided engineering in engineering design, and other software (the weakest in the industrial industry field) have significant gaps between the domestic and advanced international level (Table 4).

Table 4. Independent guarantees of basic industrial software.

Basic industrial software	Independent guarantee situation	Extent of gap between domestic and imported software
High-throughput experiment control software	Mainly domestic	A gap remains in control accuracy [32].
Computer-aided engineering	Mainly imports	Weak foundation and large gap [33]
MATLAB		Low degree of comprehensive integration application [34,35]
Meteonorm		Database resources are scattered and limited [36].
PVsyst		Highly integrated, internationally recognized [37,38]
GT-AutoLion		Lack of core technologies such as algorithms [39]
High-throughput computing software (such as Materials Studio and VASP)		Few types and insufficient computing power [40,41]
Data mining software (RapidMiner)		Lack of highly integrated data mining software [42,43]

4 Development goals and key measures to enhance the basic industrial capacity of frontier new materials

4.1 Development goals

By 2025, the frontier new materials industry will have key breakthroughs in the design and manufacturing equipment for frontier new materials, and have a massive area for the manufacturing of core devices based on frontier new materials and related testing equipment to realize multifunctional, lightweight, and intelligent frontier new materials. The key scientific and technical issues in the intersection of frontier new materials and information technology can be solved by R&D of new intelligent sensor/drive-integrated frontier new materials and devices. The technology and applications will keep pace with the advanced international level, and some of them will reach the leading international level.

By 2035, the frontier new materials industry will realize the fundamental transformation of frontier new materials research and industrialization, from the experimental trial-and-error method to the fourth paradigm of data-driven plus AI science, by constructing a common and key frontier technology innovation system. By progressing from the second echelon of the global frontier new materials industry to the first echelon, it will be possible to achieve international leader on industrial innovation ability, technical equipment level, and product market share.

4.2 Key measures

4.2.1 Improvement of basic abilities in scientific and technological innovation of the frontier new materials industry

Interdisciplinary research in computational materials science, material informatics, and intelligent preparation and processing must be conducted. The original innovation capabilities on data-driven material discovery, preparation, processing, and industrial promotion technologies should be improved. Technologies such as intelligent manufacturing, intelligent additive manufacturing, and independent, efficient, and intelligent testing of frontier new materials should be developed. Interdisciplinary research teams should be established, and interdisciplinary and innovative talents should be collaboratively trained.

4.2.2 Improvement of basic support and guarantee abilities of frontier new materials industry

Basic industrial software with independent intellectual property rights, as well as efficient computing, experimentation, and AI technologies, should be developed. In addition, independent development and application of large-scale and basic precision equipment should be brought to speed. Service feedback and revolution systems for frontier new materials must also be established. Supervision for safety of supply chain for raw and auxiliary materials should be strengthened, and resource risks should be reduced by encouraging enterprises to enter the international market.

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4.2.3 Improvement of basic competitiveness of frontier new materials industry

Production, education, research integration, and innovation platforms for efficient computing, experiments, material databases, and intelligent material preparation and processing should be established jointly by enterprises, universities, and scientific research institutes. Research on efficient and cheap manufacturing technologies should also be strengthened, and flexible manufacturing technologies should be developed. Well-known material brands and invisible champion enterprises must also be cultivated.

4.2.4 Improvement of basic abilities for sustainable development of frontier new materials industry

The application of key technologies, such as efficient computing and experimentation, data-driven material invention, preparation, and processing, should be promoted in the entire ecological lifecycle design and multi-dimensional evaluations of frontier new materials. In addition, frontier new material technologies for clean production, green manufacturing, recycling, and remanufacturing should be developed.

4.2.5 Strengthening infrastructure construction in frontier new materials industry

A common key technology and industry promotion platform for frontier new materials need to be established along with a product quality support and improvement system. Furthermore, the construction of future networks and data centers should be accelerated. Advanced industrial software and testing equipment should also be developed to elevate the basic level of equipment for the frontier new material industry.

4.2.6 Improvement of ecological environment in frontier new materials industry

Supporting policies for the development of the material industry should be formulated and the cultivation of interdisciplinary talent should be encouraged. Policies and regulations regarding scientific and technological innovation, investment, and financing of frontier new materials should be improved. Private investments on frontier new materials industries should also be encouraged. Innovative development models for these materials and their common key technologies should be established to form an industrial ecology supported by the platform and has large-scale and multilevel cooperation and sharing.

5 Countermeasures and suggestions

5.1 Enhancing the basic capabilities of the frontier new materials industry through material genetic engineering

5.1.1 Establishing an innovation technology system for frontier new materials

In view of the weak R&D capabilities in the field of frontier new materials and the lack of basic innovation capabilities for key materials, researchers should aim at the strategic and basic problems. These problems include the lack of high-efficiency computational design methods and software for materials, inadequate high-throughput experiments and independent experimental technologies, and incomplete material behavior characterizations across spatiotemporal scales, databases, and large data technologies. Furthermore, there is a need to strengthen basic and applied research to enhance the original innovation capabilities in the field of frontier new materials.

5.1.2 Developing intelligent design technologies for frontier new materials

Considering the inadequacies of innovative design in the field of frontier new materials, researchers should focus on developing intelligent design technologies for frontier new materials. Computer science, the Internet, cloud computing, and other technologies can be combined to form a material intelligent-design technology that integrates efficient material computing, high-throughput experiments, and material data, thereby promoting the rapid development of the basic capabilities of the frontier new material industry.

5.1.3 Constructing promotion centers for developing the material genetic engineering industry

Aiming at the commercialization and large-scale application of key software and equipment for material genetic engineering, industrial objects should include a high-efficiency computational simulation software for material design and production, experimental equipment for high-throughput preparation and characterization of materials, and material data and data technology software. A development promotion center for the material genetic engineering industry should also be constructed. In general, China should promote industrial development and large-scale application of the corresponding key technologies in material genetic engineering.

5.1.4 Exploring new models to train innovative talents in materials genetic engineering

In view of the shortage of skilled personnel and lack of motivation for development in the field of frontier new materials, a reform of the materials science and engineering education systems should be conducted. A new education system of material subjects should be developed and a new model for talent training should be constructed to organically integrate materials science theory, computational materials science, and materials informatics into the system. A group of comprehensive, innovative, and talented individuals with new ideas and concepts for material genetic engineering should be created and allowed to master new methods and technologies. Sufficient intellectual support should also be provided to improve basic industrial capabilities of the frontier new materials.

5.2 Frontier new material industry planning under the new, double-cycle development pattern

5.2.1 Promoting a leapfrog development of frontier new material industry with dynamic comparative advantages

Certain key areas of the frontier new material industry, such as semiconductor and high-end chip R&D, represent the inadequacies in the industrial system of China. China should use its dynamic comparative advantages entirely to catch up to market and technology, simultaneously. With coping measures such as increasing investment in talent training and enhancing the competitiveness and free mobility of the labor market, China can promote an accumulation of human resources in the frontier new material industry, improve the structure of human resources, and increase its production efficiency. The stakeholders should also coordinate when planning an establishment of frontier new material industries in various regions, conduct position optimization and differentiated layouts based on regional development endowments, and control and curb follow-up investments using a top-level design.

5.2.2 Cultivating an innovative community for frontier new materials industry

The role of enterprises, as the main body of frontier new material innovation, should be strengthened, and enterprises should be encouraged to increase investments in the R&D of frontier new materials to gradually complete the transition from habitual tracking and imitation to an active and original innovation. By relying on key scientific research institutions, such as the Beijing Advanced Innovation Center for Materials Genome Engineering, it will be possible to establish a frontier new material basic R&D center, frontier new material industry common key technology R&D center, and frontier new material service evaluation and testing center. A frontier new material industry service measurement system should also be formed, and an innovation foundation and development-sharing platform for frontier new materials should be built. Establishing a frontier new material industry innovation community in this manner will shorten the research cycles for the materials and reduce research costs.

5.2.3 Building a collaborative innovation system for frontier new materials industry

The rapid development of the frontier new materials industry depends on the effective demand of the downstream application market. It should fully rely on the regional market system, establish a market application-oriented frontier new material industry development mechanism, and implement product innovation based on a rapid market response. A reasonable deployment of short-term and medium- to long-term economic development plans should promote considerable innovative demands from downstream terminals and an upgrade and improvement of the frontier new material industry chain.

5.2.4 Integrated development of frontier new material industry and innovation chains

China has reliable production and supporting capabilities and a relatively complete production support system to expand and strengthen the frontier new material industry. The stakeholders should associate importance to and encourage technological innovation for the frontier new material industry with significant correlation to the supply chain, processing technologies, and applications. Moreover, they should build a technological platform for industrial integration and form a new and integrated development model for the frontier new material industry system. They should also integrate the discrete frontier new material industry value chains and encourage the upstream and downstream of the industry chain to cooperate in tackling the key problems. Generally, the aim should be to improve innovation and production efficiency, as well as international competitiveness, of the frontier new material industry.

5.3 Frontier new material industry planning in the context of carbon peak and carbon neutralization

5.3.1 Accelerating the development of efficient energy conversion in frontier new material industry

China has achieved outstanding performance in various fields of frontier new materials for energy conversion; for example, the number of scientific papers and patent applications are leading in the world, and the scale of related enterprises grew rapidly. In this stage, most of the frontier new materials energy conversion fields in China are in a critical period of transitioning, from following to leading. Relevant industries should focus on global market trends and seize strategic opportunities on carbon peaking and neutrality. In addition, they should emphasize priority

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development areas, encourage active linkages, and strive for a steady progress.

5.3.2 Strengthening top-level design of frontier new materials

The stakeholders should conduct organized scientific research and guide the progress in key areas of the entire process to progress step by step according to a plan. The industrialization of achievements in the frontier new materials should be accelerated, and a public R&D and auxiliary verification platform running through industry, universities, and research institutes should be established. An efficient transformation should also be realized from scientific research achievements, to technological incubation and batch applications. The core technologies and intellectual property layouts of frontier new materials should be strengthened while simultaneously improving the innovation capabilities of research institutions and enterprises to establish independent intellectual property rights and avoid potential risks.

5.3.3 Building an open and shared service platform for innovation and development of frontier new materials

Practitioners should rely on key scientific research institutions to receive the complementary advantages from each unit and establish a frontier new material innovation and development platform. The division of labor and subsequent cooperation among scientific research institutions should also be encouraged to shorten the R&D cycle of frontier new materials. There is a need to master development trends of foreign frontier new material research, development, and industrialization. Efforts should focus on the key points of domestic industrial development, strengthening research on development strategies for the frontier new material industry, and macro guidance for its development in various regions. A guidance catalogue and investment guide should be formulated for the development of frontier new material industries, such as in the energy conversion field. Massive data technology should also be pursued to promote cost reductions and increase in efficiency of R&D, promotion, and application of frontier new energy materials.

5.4 Development of testing and characterization ability of self-controlled frontier new materials

5.4.1 Research on common key technologies for testing and evaluation capabilities of frontier new materials

Practitioners should focus on testing and evaluating the entire lifecycle of frontier new materials, achieve breakthroughs in it, and develop advanced instruments and equipment. In-depth research on frontier new material analysis and testing, application evaluation, lifecycle prediction, failure analysis, and other methods should be conducted to form national and industry standards. Research on the comprehensive performance testing of frontier new materials should be strengthened, talent training and intelligence recruiting should be enhanced, and the problems of weak and low levels of testing and evaluation ability of frontier new materials should be addressed.

5.4.2 Building an Internet platform for the testing and evaluation of frontier new materials

The stakeholders should establish an Internet service platform to test and evaluate frontier new materials. With the help of this platform, they should be able to collect and gather the test and evaluation equipment and data resources scattered across various institutions, enterprises, universities, and scientific research institutes across the country. Efforts should be made to build a test and evaluation equipment library and database and promote its sharing and utilization, focusing on solving the problems on scattered and low utilization of cutting-edge new material testing and evaluation equipment, lack of data aggregation and sharing, and so on.

5.4.3 Improving public service abilities of frontier new materials for testing and evaluation

Efforts should be made to build an advanced international testing and evaluation platform and to integrate and form a frontier new material testing and evaluation service system to support the sustainable development of the industry. By relying on the existing national new material testing and evaluation platform, the China Advanced Materials Testing and Evaluation Alliance, and other key institutions, a market-oriented mechanism and collaborative innovation model can be established. Furthermore, the corresponding testing and evaluation capabilities and Internet service platform can be used to provide a one-stop service platform for public services such as inspection and testing, consultation, training, certification, and evaluation. The stakeholders can actively carry out brand-building and international cooperation and promote the improvement of common technologies and industrial development levels for the testing and evaluation of frontier new materials.

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